TITLE: Test and Evaluation of the Man-Machine Interface between the Apache Longbow and an Unmanned Aerial Vehicle

Test and Evaluation of the Man-Machine Interface Between the Apache Longbow™ and an Unmanned Aerial Vehicle

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ABSTRACT

The Boeing Company is studying a concept that involves teaming a manned rotorcraft, the Apache Longbow™, with a unmanned air vehicle (UAV). During 1997 Boeing developed a preliminary man-machine interface between the Apache Longbow and an unmanned air vehicle. An early assessment of the man-machine interface in a virtual simulation environment was conducted. The study concentrated on the effects of crew workload during manned-unmanned teaming operations and acceptability of the design in terms of presentation of the data, functionality, and utility. A limited assessment of operational measures of effectiveness was also conducted. Subject pilots were satisfied with the man-machine interface, did not experience task overload and were able to perform UAV control tasks. Subjects did experience some difficulty with target acquisition and tracking, however. Initial data suggests that the potential exists to detect targets beyond the organic sensor range of current attack/reconnaissance rotorcraft without being exposed to threat detection.

INTRODUCTION

The ability to link a UAV to a manned reconnaissance/attack rotorcraft has the potential of substantially improving mission effectiveness during reconnaissance and attack operations. UAV electro-optical and FLIR sensors provide for surveillance, targeting and battle damage assessment functions. Extended sensor range offered by the UAV remote sensor capability may provide increased situational awareness and reaction time, which has the potential to increase the lethality, survivability, and mission effectiveness of attack/reconnaissance teams. A major concern is the level of crew interaction required and the workload placed on the crew for effective manned-unmanned teaming operations.

Boeing operations research analysts designed and implemented a virtual simulation test to assess the preliminary man-machine interface for the Apache Longbow developed for the manned-unmanned teaming concept. The two week test was a part of an on-going Boeing internal research and development (IRAD) project aimed at exploring the effectiveness of teaming the Apache Longbow with unmanned air vehicles. The virtual simulation testing described in this paper was conducted in the AH-64D Engineering Development Simulator (EDS) at the Boeing Company in Mesa, Arizona.

OPERATIONAL CONCEPT

The initial IRAD focus is to develop a prototype manned-unmanned teaming capability for Apache Longbow. Based on the operational concept developed, the crew employs the UAV once it is in the mission profile. The crew does not takeoff, land, or "fly" the UAV. Conceptually the manned aircraft crew would employ one of three levels of UAV control. These levels of control include:

- Associated Mode. UAV navigation and sensors are controlled by a ground station. The manned aircraft crew is able to view UAV sensor video. The crew has no control over the UAV.
- Dedicated Mode. UAV navigation and sensors are controlled by a ground station. However, the ground crew responds directly to manned aircraft taskings. The manned aircraft crew is able to view UAV sensor video.
- Coupled Mode. UAV navigation and sensors are under direct control of the manned aircraft crew.

The focus of this test was assessment of the man machine interface. Therefore, the test scenario was limited to employment of the coupled mode to fully task the crew during the test. Further study and assessment of employment modes and their effectiveness is recommended, as it was not within the scope of the activity discussed in this paper.

Presented at the American Helicopter Society 54th Annual Forum, Washington, DC May 20 - May 22, 1998.

Paper presented at the RTO SCI Symposium on "Warfare Automation: Procedures and Techniques for Unmanned Vehicles", held in Ankara, Turkey, 26-28 April 1999 and published in RTO MP-44.

AH-64D MAN-MACHINE INTERFACE

The existing AH-64D Apache Longbow crewstation design was modified to provide a man-machine interface for operation of UAV navigation equipment, sensors and air vehicle systems for employment in the manned-unmanned teaming concept. This section provides a brief description of the UAV controls and displays that were integrated into the EDS crewstations.

The preliminary man-machine interface design incorporates current sensor, flight, and operational capabilities of both the Apache Longbow and the Hunter UAV, manufactured by TRW and IAI. Functional requirements for the man-machine interface were developed by Boeing operations research analysts and were based on the operational concepts developed under the IRAD. The Boeing design team included crewstation design engineers, an engineering test pilot, software engineers and operations research analysts. A TRW software engineer and UAV training and mission specialist were consulted by the team throughout the project.

UAV Controls and Displays

UAV controls and displays are integrated into the multifunction displays (MFDs) in both crewstations and into the Optical Relay Tube (ORT) controls in the Co-Pilot Gunner (CPG) crewstation. MFD controls are consistent with the current AH-64D controls and displays philosophy and allow for establishing a communication link to monitor and/or control the UAV and sensors, as required. The primary control of the UAV Multi-mission Optronics Stabilized Payload (MOSP) sensors is allocated to the CPG station via the ORT handgrips (Figure 1).

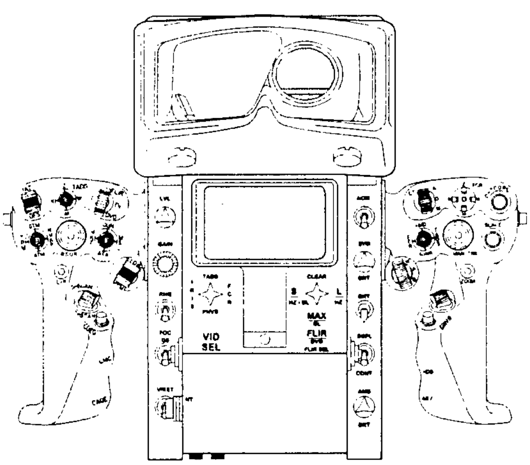

Figure 1. CPG Optical Relay Tube (ORT)

UAV Control Functionality

UAV sensor video is typically presented on the UAV page on the MFD overlaid by a minimum of UAV control buttons and sensor targeting/UAV flight parameter status information (Figure 2). UAV sensor video may also be presented under any MFD page format in the same manner as any AH-64D sensor video is currently displayed. UAV sensor video may be displayed to the CPG on the ORT video display as well. Symbology regarding UAV position and sensor orientation is also displayed on the MFD Tactical Situation Display (TSD) page (Figure 3). UAV symbology was not fully integrated into the TSD in time for this test. Further assessment is recommended once the integration is completed.

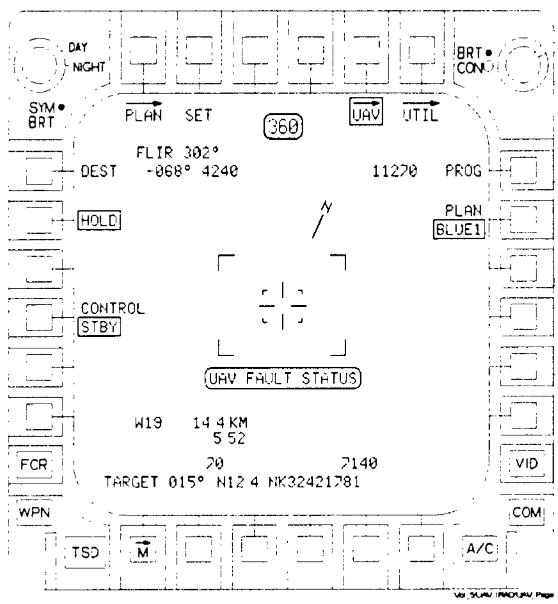

Figure 2. UAV Page

UAV sensor video may be monitored by one or more aircraft by enabling the UAV receiver/transmitter (R/T) on the appropriate channel. While sensor video imagery may be monitored in either crewstation and by other Apache Longbow team members, only one Apache Longbow is in control of the UAV at any one time during a mission.

Once the R/T has been enabled and a downlink established, one of two control modes may be selected by the crew to enable the uplink and control of the UAV. When control mode - *standby* is selected, the crew may select one of three UAV flight modes. However, control of UAV sensors is not enabled. Flight control of the UAV is via command inputs to the UAV auto-piloting system.

The UAV can be commanded to fly one of three flight modes:

- Plan mode. UAV flies one of six programmed mission plans.
- Destination mode. UAV flies to a specific waypoint with sensors oriented to a specific target.
- Hold mode. UAV flies a holding pattern at the current location with the sensors oriented to a specific target

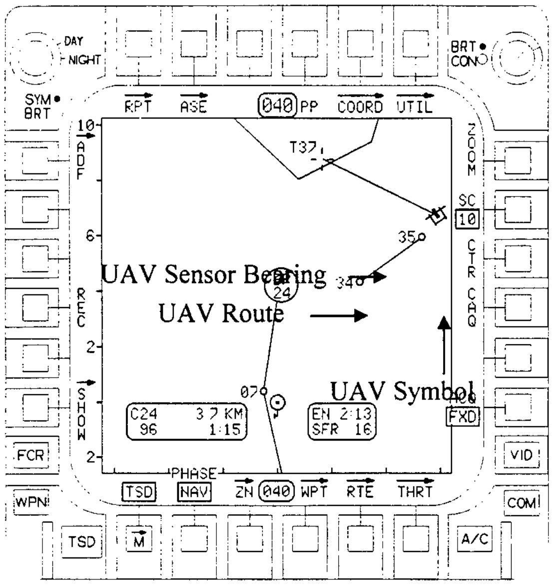

Figure 3. TSD Page

When control mode - *on* is selected, the crew has control of the UAV sensors as well as the UAV flight mode. By toggling between *standby* to *on* using either an ORT right handgrip control or a UAV page control, the CPG has immediate control over either the TADS or UAV sensors, as desired. UAV sensors are employed using the same ORT switch controls that are used to operate the AH-64D Target Acquisition Designation Sight (TADS) sensors. Based on the UAV control mode, these controls will operate either the TADS sensors (control mode *standby*) or the UAV sensors (control mode *on*). These functions include the capability to:

- select sensors and fields of view
- record sensor video imagery
- manually track targets
- lase targets to obtain range for target store data or for weapons engagement

As with other Apache Longbow systems, control settings and programmed mission data associated with the UAV and sensors will be entered into the data transfer cartridge at the Aviation Mission Planning Station (AMPS) and ultimately uploaded to the mission processors via the data transfer receptacle. This data is capable of being modified as necessary during flight.

DESCRIPTION OF TEST

This test had three objectives: (1) Assess the preliminary man-machine interface; (2) Collect limited objective data to address mission effectiveness; and (3) Provide initial data to be used to further develop conceptual Tactics, Techniques and Procedures (TTP).

Test Facilities

The two week assessment was conducted at the Apache Longbow Engineering Development Simulator (EDS), located at the Boeing-Mesa facility. It consists of pilot and CPG crewstations, each located in a separate 20 foot dome. Each crewstation is configured to represent the Apache Longbow crewstation design and is provided with baseline AH-64D functionality, an out-the-window visual display, sensor display, flight dynamics, and interaction with the central Tactical Mission Computer System (TMCS). The TMCS provides weapons and sensor capabilities, controls the threat, and accounts for all engagements involved in a tactical situation.

Test Subjects and Training

Four test subjects, all AH-64D Apache Longbow qualified and current pilots, participated in the study. Three participants were U.S. Army instructor pilots assigned to A Company, 1/14 Aviation Regiment, located at the Boeing facility in Mesa, Arizona and one pilot was a Boeing company test pilot.

Test subjects received training concerning the manned-unmanned teaming concept and the man-machine interface prior to conduct of the test runs. Training consisted of four hours of academic instruction and three 1.5 hour periods of simulator flight instruction. The same terrain and threat database were employed for training and test runs. However, different scenarios and supporting graphics, as well as the UAV flight route, were employed during training in order to minimize the impact of learning effect on the test runs.

Simulation Test Environment

The test was conducted using the standard Combat Simulation System Evaluation (CSSE) central European terrain database. This database consists of rolling terrain populated by villages, streams and forest tree blocks. The missions took place during daylight conditions. The threat consisted of elements of a Motorized Rifle Battalion deployed for attack.

The test was conducted in a part-mission environment. Initial conditions positioned the aircraft at the start point of the mission with all systems operational. The test consisted of eight simulator runs, with each of the four test subjects completing two test runs each. Each test subject flew as the CPG and used the modified man-machine interface design developed for manned-unmanned teaming. A Boeing simulator pilot flew in the pilot station for each of the test runs.

One vignette was used for the test. The crew was tasked to perform zone reconnaissance while employing a UAV for surveillance of an area adjacent to the zone. The CPG was required to receive handover of UAV control from the ground control station, verify UAV sensor operation, and assign the UAV a preplanned route for the mission. The aircraft then departed for the reconnaissance. During the mission, the CPG was tasked to conduct surveillance of specific areas of interest using both the organic TADS sensors and the UAV sensors. Normal voice and data radio traffic was simulated to increase task loading. The test vignette overlay is provided in Figure 4.

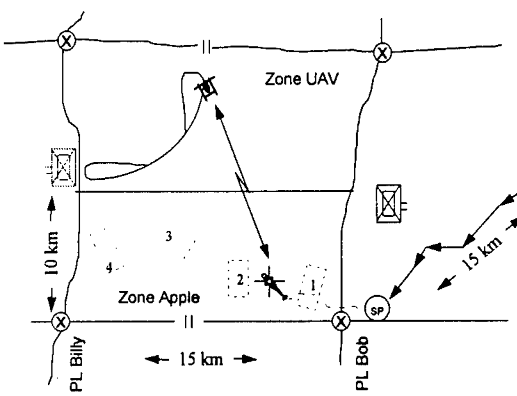

Figure 4. Test Vignette Overlay

Standard U.S. Army nap of the earth (NOE) operations and Tactics, Techniques and Procedures (TTP) as described in FM 1-112, *Attack Helicopter Operations* and FM 1-117, *Air Reconnaissance Squadron* were employed.

Conduct of Trials

Prior to each test run, each test subject and the Boeing simulator pilot received a mission briefing to understand the tactical scenario and objectives of the test. Each test run started with the test subject sitting in the cockpit wearing normal flight gear. The flight helmet and helmet mounted display were not worn by the test subjects, as these components were not a factor in the evaluation of the man-machine interface. Initial conditions for the EDS placed the aircraft on the ground running at the start point of the ingress route. The EDS pilot and CPG crewstations were operated in an integrated mode to permit the CPG test subject and Boeing simulator pilot to function as a single AH-64D crew.

RESULTS

The results of this test include subjective and objective data. Subjective data were collected to address the adequacy of the man-machine interface as well as to provide a limited assessment of the concept of linking a UAV to a manned rotorcraft. Objective data were collected from observations tracked during the trials and real-time data collection from the Apache Longbow EDS. These data were used to assess the functionality of the design and to support the limited assessment of the concept.

The data were gathered from data recorders, task performance tracking sheets, notes taken during the trial, pilot questionnaires, and mission debriefs. Pilot opinions regarding positive and negative attributes of the display formats and symbology, observations concerning the operational difficulty using the interface, and operational employment were of key interest.

Objective Data

Crew Task Performance. Performance of UAV control tasks were monitored during each trial and errors were counted using a tracking sheet. The objective was to identify tasks with higher levels of difficulty based on the error counts. Tasks with higher error counts may indicate a need to further assess design features and functionality to reduce the difficulty associated with performance. As shown in Table 1, the tasks which the crew had the greatest difficulty performing were: manually searching, manually tracking, (in narrow and zoom fields of view only) and slaving the UAV sensor to the target. Because manual search and manual track are not discreet tasks, a weighting scale was developed to rate the performance of these tasks for counting as errors. The higher number of task errors for these two tasks should be weighed against the fact that search and track tasks were performed far more than any other tasks. Design functions supporting manual search and manual tracking should be more closely examined during completion of the man-machine interface integration effort and re-assessed in future studies.

Table 1. Summary of Crew Error Tracking

Task Area	Total # of Errors
Perform UAV Initialization	0
Perform UAV Handover	0
Perform UAV Navigation	1
Perform UAV Sensor Operational Checks	0
Perform UAV Sensor Manual Search	6
Perform UAV Sensor Manual Tracking	15
Perform UAV Sensor Target Slaving	4
Perform TADS UAV Target Acquisition	0
Perform UAV LRFD Operations	0
Perform UAV Target Storing	0

Operational Measures of Effectiveness. Limited data were collected to make a preliminary assessment of the effectiveness of the manned-unmanned teaming concept. Objective real-time data were captured for six of the eight trials. The measures of effectiveness for the test and results are described below.

- UAV Target Detection Range. The average distance from Apache to the threats when the threats are visually detected by UAV sensors was 13.4 km. However, it would not have been possible for the crews to detect threats beyond 20 kilometers due to the nature of the test scenario. Although the objective was not to see how far or how quickly the crews would detect threat, it is still worth noting that crews detected threats beyond the organic sensor capabilities of current attack and reconnaissance rotorcraft.
- Number of Targets Acquired. The total number of possible targets was seven. However, the actual number presented to a crew during a trial varied due to EDS image generator performance. Regardless of the number of targets presented, once the crew detected the threats using UAV sensors, all threats were acquired.
- Exposure Time. In all but one of the trials, Apache was not exposed to threat line-of-sight. During the one trial in which Apache was exposed, the exposure time was approximately 11 seconds in duration at a range of 9.7 km from the threat.

Subjective Data

The primary purpose for collecting subjective data was to document pilot feedback concerning the acceptability of the preliminary man-machine interface. A questionnaire was developed with four areas of consideration for the design, to include:

- Presentation of Data
- Design Functionality
- Design Utility
- Crew Workload

Subjective data concerning operational concepts were also gathered.

Presentation of Data, Design Functionality, Design Utility. Following each of the test trials, the test participants were asked to rate the acceptability of the man-machine interface. The rating scale for these data are 1.0 to 5.0, with 1.0 "terrible/of no use" and 5.0 being "excellent/extremely useful". The ratings were then compiled to present an overall picture of the man-machine interface acceptability. Figure 5 presents the average scores of the interface, rated by the subject pilots in four (4) areas of concern: (1) UAV Handover and Set-up phase; (2) UAV Sensor Operations; (3) UAV Status; and (4) Overall Concept Summary. This figure is a graphical representation of the tabular results.

As shown in Figure 5, average ratings exceeded 4.0 (good/of considerable use) in all four areas of consideration. From a total of 59 questions, seven rated in the 3.0 to 3.9 acceptability range (only fair/of use), and no ratings were received below the 3.0 acceptability range. The two questions/categories which rated the lowest were "Rate your situational awareness of a UAV real time position relative to your Apache location." receiving an average score of 3.5 and "Rate the usefulness of modifying UAV altitude.", receiving an average score of 3.4. The questions or areas receiving the highest ratings were "Rate the utility of UAV sensor video underlay on the MFD.", scoring an average of 4.8, "Rate the usefulness of viewing UAV video on the MFD - UAV page.", scoring an average 4.8, and "Rate the usefulness of the UAV hold mode", receiving a 4.9 average score.

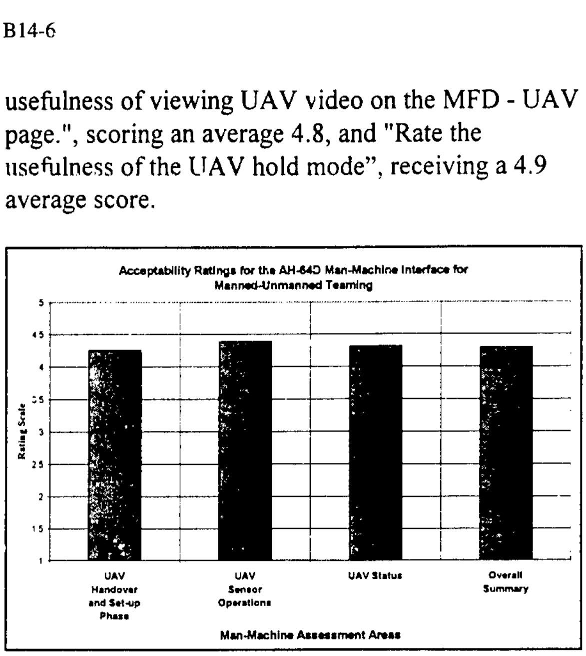

Figure 5. Man-Machine Interface Ratings

Pilot comments/suggestions concerning the design acceptability were gathered during the mission debriefs. Pilot comments were mainly concerned with presentation of data on the TSD and UAV sensor tracking. The most common comments concerning the TSD were suggestions to include the UAV location/bearing and UAV route on the TSD. These features are a part of the preliminary design, but were not integrated in time for the virtual simulation test. As these features are integrated into the design, additional study and assessment is recommended. With regard to UAV sensor tracking, two pilots expressed difficulty with tracking in narrow/zoom fields of view. These comments are consistent with the objective data concerning target acquisition and tracking noted in the previous section. Further investigation into integration of the UAV sensor tracking capabilities in the man-machine interface is recommended.

Work Load Assessment. A modified Task Load Index (TLX) was used to assess crew workload in relation to the acceptability of the man-machine interface. Figure 6 presents the subject ratings in six areas of task loading. The rating scale for these data are 1.0 to 10.0, with the lower score of 1.0 representing minimal work load and a rating scale of 10.0 representing task saturation. A rating scale of 1.0 to 10.0 is used versus a scale of 1.0 to 5.0 to provide the necessary granularity for accurate measures. The rated areas are as follows:

(1) Mental demand. How much mental and perceptual activity was required.

(2) Physical demand. How much physical activity was required.

(3) Temporal demand. How much time pressure was felt by the subject due to rate or pace at which the tasks or task elements occurred.

(4) Performance. How successful the subjects felt they were in accomplishing the goals of the task set by the experimenter (or themselves).

(5) Mental and Physical effort. How hard the subjects felt they had to work (mentally and physically) to accomplish their level or performance.

(6) Frustration. How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent the subjects felt during the task.

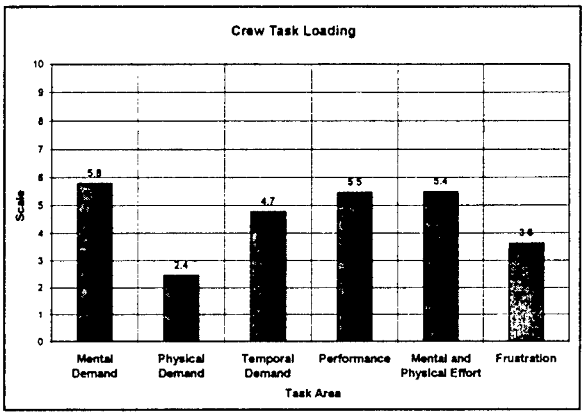

Figure 6. Crew Task Loading

As shown in Figure 6, the areas which the crew felt the highest demand were: (1) Mental Demand; (2) Performance; and (3) Mental and Physical Effort. The scores for these areas were between 5.0 and 6.0, well below the score of 10.0 which would represent a high demand on the crew member. The data compiled from the Task Loading questionnaire resulted in an average score of 4.6. According to the numerical ratings given and based on interview comments, the test subjects did not experience any task overload using the man-machine interface to employ the manned-unmanned teaming concept.

Pilot subject comments concerning work load reveal that they did not feel that they experienced task saturation or work overload. Comments also stated that with each day, the system was easier to use and with more experience, tasks relating to the interaction with a UAV would come naturally. One subject commented, "There was no added work load specifically due to the UAV. I received IDM traffic, radio calls, but you just prioritize tasks like if you were using your TADS. No difference with UAV sensors as with TADS . . ."

Pilot Comments Concerning Concept of Operations. Specific questions were asked the test subjects during the debriefing of each test run to obtain aircrew feedback and to ferret out new ideas for the manned-unmanned teaming concept. Test subject comments are summarized below.

- UAV Distance During Reconnaissance. Subjects felt that the optimum position for the UAV during Apache reconnaissance/security missions would be approximately 10 km in front of or to the flank of the Apache.
- UAV Control During Reconnaissance. Direct control of the UAV by the manned aircraft is most suitable when the UAV is providing security for an attack/reconnaissance mission. When the UAV is performing reconnaissance in an area adjacent to the manned aircraft as an economy of force, however, control should be maintained by the UAV ground control station. The Apache crew can still monitor the UAV video live feed without direct control.
- Applicability of UAV During Movement to Contact. The UAV may be very well suited as a remote sensor during movement to contact missions. One subject commented, ". . . turns a movement to contact into a deliberate attack. . . . allows you to almost remove a movement to contact as a scenario." Hence, the UAV makes the 'contact', and the manned aircraft conducts the deliberate attack.

CONCLUSION

The Boeing Company has performed an early assessment of the preliminary man-machine interface for developed for teaming the AH-64D Apache Longbow with an unmanned air vehicle in a virtual simulation environment. This man-machine interface is based on existing AH-64D crewstation design and UAV operational and functional characteristics.

(1) Subjects rated the acceptability of the man-machine interface as at least "good" in terms of Presentation of Data, Design Functionality, and Design Utility.

(2) Subjects did not experience any task overload using the man-machine interface during test runs.

(3) Objective and subjective data indicate that subjects did experience some difficulty with manual target search and tracking in the narrow and zoom fields of view.

(4) A limited assessment of operational measures of effectiveness indicate that the manned-unmanned teaming concept has the potential to allow crews to acquire targets beyond the range of organic sensors without being exposed to threat forces.

(5) Subject comments indicate that the manned-unmanned teaming concept has applicability for attack and reconnaissance missions.

(6) UAV sensor tracking and target acquisition features should be examined as the design is completely integrated.

(7) Further studies and assessments should be performed once the complete preliminary man-machine interface is integrated into the AH-64D crewstation.

(8) Further study of the manned-unmanned teaming concept to include mission effectiveness and employment modes is recommended.